AD 713170

AFCRL-70-0422
27 JULY 1970
ENVIRONMENTAL RESEARCH PAPERS, NO. 327

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

Auroral Oval Plotter and Nomograph for Determining Corrected Geomagnetic Local Time, Latitude, and Longitude for High Latitudes in the Northern Hemisphere

JAMES A. WHALEN

United States Air Force

31

This document has been approved for public release and sale; its distribution is unlimited.

Qualified requestors may obtain additional copies from the Defense Documentation Center. All others should apply to the Clearinghouse for Federal Scientific and Technical Information.

AFCRL-70-0422
27 JULY 1970
ENVIRONMENTAL RESEARCH PAPERS, NO. 327

IONOSPHERIC PHYSICS LABORATORY PROJECT 5631

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

Auroral Oval Plotter and Nomograph for Determining Corrected Geomagnetic Local Time, Latitude, and Longitude for High Latitudes in the Northern Hemisphere

JAMES A. WHALEN

United States Air Force

Abstract

A nomographic computer is presented which graphically converts geographical coordinates and universal time into geomagnetic coordinates and geomagnetic local time in the Corrected Geomagnetic system of Hultqvist. The computer is formulated as a map of high latitudes in the Northern Hemisphere on which the position of the auroral oval can be projected directly for any time of day, for any magnetic activity, with account being taken of seasonal variation of the geomagnetic local time coordinate. Instructions for its use, discussion of its accuracy, and examples of its application are given.

Contents

Auroral Oval Plotter and Nomograph for Determining Corrected Geomagnetic Local Time, Latitude, and Longitude for High Latitudes in the Northern Hemisphere

1. INTRODUCTION

The coordinates of geomagnetic latitude and geomagnetic local time form a very useful basis for ordering geophysical phenomena which depend on the solar-magnetospheric interaction. These are the coordinates of the auroral oval and many other phenomena, and form the logical basis in which to map the boundary interactions between magnetosphere and ionosphere.

The conversion to these coordinates from geographic coordinates and universal time is tedious even for observatories with fixed locations. For a moving observatory with rapidly changing location, the practical problem of coordinate transformation particularly in real time is almost insurmountable without the use of an on-line computer. This is the case for the AFCRL Airborne Ionospheric Observatory, an NKC-135 jet aircraft instrumented with an ionospheric sounder, photometers, and all sky cameras (Buchau et al, 1969).

Thus the Auroral Oval Plotter has evolved out of the necessity for rapid coordinate transformation, and is a descendant of Akasofu's mechanical auroral oval model (Private Communication, 1968). Use of the Plotter has made it possible to approach auroral observation by conceptually navigating in the auroral oval frame of reference.

(Received for publication 10 July 1970)

2. CHOICE OF COORDINATES

The magnetic field of the earth is approximately that of a dipole, yet the departures from the dipole particularly in polar regions are significant enough to have inspired a large variety of coordinate systems. Pendorff (1968) gives a survey of many of them.

This report adopts the corrected geomagnetic (C.G.) system of Hultqvist (1958a, 1958b), using the coordinates computed by Hakura (1965). The details of the formulation of the C.G. system appear in the above references and will not be treated here.

This system has gained wide acceptance by many workers, and the Feldstein and Starkov (1967) auroral oval is formulated in it. Although derived from measurements of the earth's magnetic field made in 1945, it has been successfully applied to the organization of auroral and related data for a long period of time. Table 1 lists examples of the uses of the C.G. system including: date of the observations; phenomena studied; hemisphere, north or south (N+S means data from both hemispheres are combined to form a consistent whole); which of the C.G. coordinates are employed (latitude, longitude, or longitude-local time, the latter two being inter-dependent).

The most recent observations find that the C.G. latitude of the noontime aurora is the same in 1969-1970 (Buchau et al, 1970) as it was in 1957-1958 (Feldstein and Starkov, 1967) as well as in 1963 (Sandford, 1968), 1967 (Buchau et al, 1969), and in 1968 (Whalen et al, 1970). This indicates the stability of the C.G. coordinate system - auroral phenomena relationship which is of specific interest to this work. These measurements, coupled with the magnetic measurements performed as early as 1932, indicate a very desirable stability of the C.G. system spanning nearly four decades.

In addition, the C.G. system has been compared with other systems and found superior. The tests have been the plotting of the data in each system, and in each one the C.G. system has been found to be the more consistent in ordering the data. Table 1 shows those instances noted by asterisk; the systems compared are the auroral and eccentric dipole in the case of Sandford (1963), and centered dipole for the others.

No comprehensive comparison of geomagnetic systems is attempted here, but these examples do illustrate the basis for choosing one system over another. In addition, Table 1 shows that Hultqvist set a commendable example in assuming the burden of proving the value of the C.G. system which he originated.

Table 1. Examples Illustrating the Time Span of the Utility of the C.G. Coordinate System

Date Of Observational Data	Topic Of Investigation	Hemisphere	Latitude	Longitude	Longitude Local Time	Reference
1932-33	*Magnetic disturbance at auroral latitudes.	N	X		X	Mayaud (1960)
1932-33	*Magnetic disturbance at auroral latitudes as a function of solar inclination angle to magnetic equator.	N+S	X		X	Fukushima (1965)
(1945)	(Magnetic field measurements on which C.G. system is based.)					Hultqvist (1958a, b)
1950-53	*Magnetic time dependence of auroral zone currents.	N			X	Hultqvist and Gustafsson (1960)
1957-58	Discrete auroral oval.	N	X		X	Feldstein and Starkov (1967)
	*Magnetic disturbance at auroral latitudes as a function of solar inclination angle to magnetic equator.	N+S	X		X	Fukushima (1965)
	Aurora (discrete and mantle) and airglow.	S	X		X	Sandford (1968)
	*Shape of auroral isochasms.	N	X	X		Hultqvist (1959)
	*Equatorward boundary of PCA.	N	X	X		Hakura (1964, 1965)
	Conformity of auroral arc orientation to oval.	N	X		X	Gustafsson (1967)
1960	Equatorward boundary of PCA.	N	X	X		Hakura (1964)
1963	*Aurora (discrete and mantle) and airglow.	S	X		X	Sandford (1968)
	Conformity of auroral arc orientation to oval.	N	X		X	Feldstein and Starkov (1967)
1967	Latitude of noon aurora.	N	X		X	Buchau, Whalen, Akasofu (1969)
1968	Latitude of noon aurora.	N	X		X	Whalen, Buchau, Wagner (1970)
1969-70	Latitude of noon aurora. Continuity of the oval as a whole.	N	X		X	Buchau, Whalen, Akasofu (1970)

*Demonstration of superiority of C.G. system over other system(s).

3. C.G. LOCAL TIME CONVENTION

The definition of geomagnetic local time is quite arbitrary, since there is no regularly observable geomagnetic time-reference (although Hultqvist and Gustafsson, 1960, determined one applicable to storm-time conditions). This work adopts the "equal tempered" time convention of McNish (1936) which is widely accepted and very convenient. In this convention, the C.G. local midnight meridian is defined as that which passes through the anti-subsolar point; C.G. local time is computed from that meridian on the basis of one hour being equal to 15° of C.G. longitude.

With this convention, a particularly simple relationship exists between (1) a map of the earth in C.G. latitude and C.G. longitude, and (2) the reference frame of C.G. latitude and C.G. local time:

One is a rigid frame of reference moving within the frame of the other with the passage of universal time (U.T.). Motion is in the direction of C.G. longitude/ C.G. local time. C.G. local time is thus defined at all points of the map simultaneously at any instant of U.T., by the alignment of the C.G. local midnight meridian with the anti-subsolar point at that value of U.T.

4. DESCRIPTION OF AURORAL OVAL PLOTTER

The Auroral Oval Plotter operates according to the foregoing principle, and consists of two frames of reference:

4.1 Map of the Northern Hemisphere at High Latitudes (see Insert which contains transparent map and page of directions).

This map entitled "Geographic Coordinates Plotted in Corrected Geomagnetic Coordinates" is a polar azimuthal equidistant projection in C.G. latitude (Φ_c) and C.G. longitude (Λ_c) about the C.G. pole (at 80°N 81°W geographic). The C.G. polar-coordinate grid is not plotted explicitly, although the circles of constant C.G. latitude and radii of constant C.G. longitude can be constructed from the fiducial marks and from the values of Λ_c and Φ_c at the pole and at the margin of the map. Instead, the grid of geographic latitude and geographic longitude is explicitly shown together with the approximate land masses and the locations of some points of interest. This avoids the confusion of two overlapping grid systems which, in any case, are unnecessary for the conversion from geographic coordinates and U.T. to C.G. latitude and C.G. local time.

4.2 Auroral Oval Plot in C.G. Latitude and C.G. Local Time (Appendix A)

This is the oval of Feldstein and Starkov (1967) shown in nine versions, one for each value of magnetic index Q from 0 to 8. The three versions of the "UT Scale" marked "Dec.", "Mar.-Sept.", and "June" are correct for winter solstice, equinoxes, and summer solstice, respectively. They arise from the seasonal variation in the C.G. longitude of the anti-subsolar point for a given U.T. This point moves north or south with season at constant geographical longitude, which is not in general constant C.G. longitude but varies in the manner shown.

The map functions as an overlay of the oval plot for the desired value of Q, and pivots about an axis through the common pole. This pole is indicated by the double circle which in addition is labelled "$\Phi_c 90^o$" on the map. The map makes one complete rotation per day corresponding to the rotation of the earth; for any value of U.T. its position is determined by aligning that value of U.T. on the appropriate "U.T. Scale" (on the oval plot) with the "U.T. Index" (the dotted line on the map). This places the C.G. local midnight meridian through the anti-subsolar point at this value of U.T., and so defines C.G. local time everywhere as described earlier. C.G. latitude and C.G. local time for any point on the map are read directly from the oval plot on which the map is superimposed. In addition, the position of the oval is given with respect to any point on the map. (An approximate U.T. scale sufficiently accurate for many purposes is the C.G. local time scale as read directly from the oval plot at the point of the arrow on the U.T. Index.)

5. ACCURACY

The precision with which the C.G. coordinates can be read from the nomograph exceeds their inherent uncertainty which Hultqvist (1958b) estimates to be of the order of 50 km. Feldstein and Starkov (1967) estimate that the oval boundaries have an uncertainty of about 1.0^o of latitude. The oval itself is derived from observations averaged over C.G. local time intervals of ± 2 hours observation.

An additional uncertainty arises from the possible variation of the latitude of the noon aurora with season, or more specifically with "tilt angle" between magnetic axis and earth-sun line. Fukushima's (1965) work indicates that in the Western Hemisphere during summer, for example, the latitude of the noon sectors of the ovals may be displaced as much as 5^o poleward of the values presented here. Maehlum (1968) finds additional evidence of this displacement from satellite observations.

6. APPLICATIONS

The Auroral Oval Plotter has evolved over the past three years chiefly through airborne studies. It is, of course, not limited to this use but has application to ground-based studies and to the conceptualization of the oval as a whole. The oval for Q=3 is a typical configuration of use in estimating the location of the aurora in general.

In flight planning the plotter can optimize aircraft navigation in the oval frame of reference given the other constraints (aircraft performance, geography, geopolitics, sun, moon, and of course the phenomena to be studied).

During flight one can monitor the expected position of the oval as an aid in maintaining his orientation with respect to the aurora, which is frequently very confusing if the flight path is at all irregular. One can rapidly determine whether the aurora is north or south of the expected position, and hence if conditions are quiet or disturbed and whether or not this necessitates changes in flight plan. In addition it is an aid in choosing between alternatives when changes in flight plans are necessary for operational reasons.

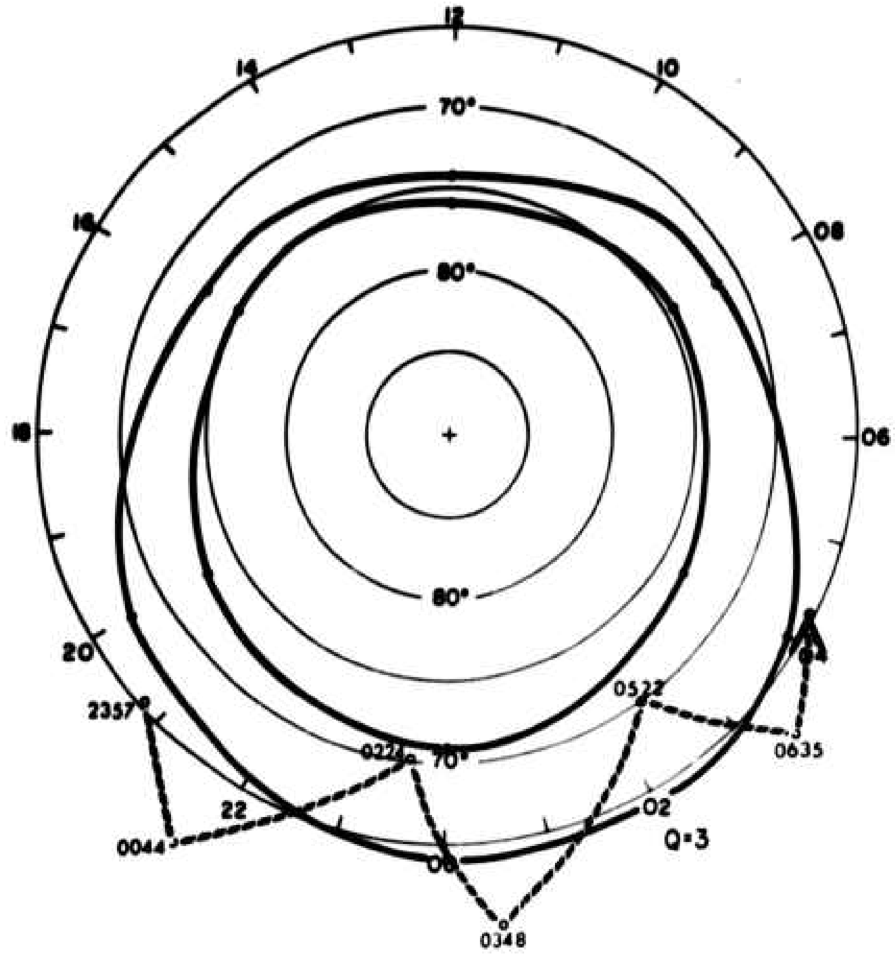
Three basic flight patterns will be illustrated: constant geographic path, constant local time, accelerated local time. Examples come from actual data flights planned, monitored, and analyzed by the aid of the auroral plotter.

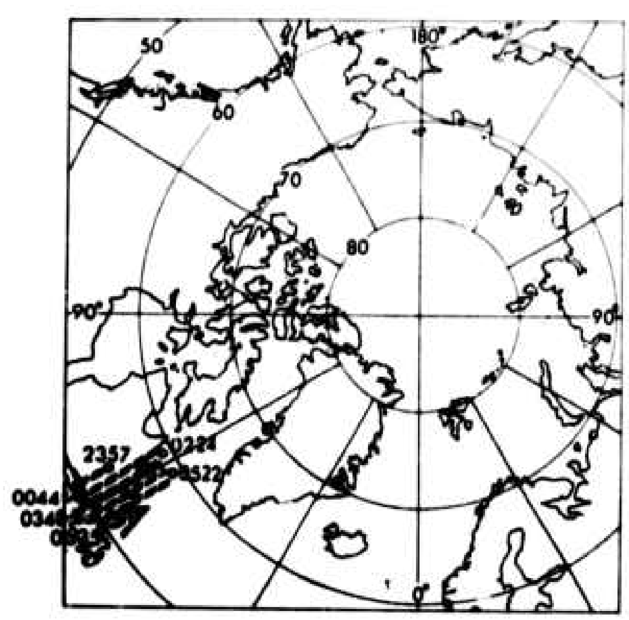
6.1 Constant Geographic Path

The simplest flight path is that which patrols back and forth along a fixed geographical path. Figure 1 (lower portion) shows a geographic map (not part of the oval plotter described in this work), on which the flight legs are actually coincident but are shown displaced from one another in order to resolve them in time. The actual route originated and terminated at Goose Bay, moving alternately north and south geographic along a constant geographic longitude. The times, given at U. T., identify specific points in the two coordinate systems. Figure 1 (upper portion) is the plot of this flight in C.G. latitude and C.G. local time superimposed on the Q=3 oval as graphically traced on the oval plot using the C.G. map described earlier.

6.2 Constant C.G. Local Time

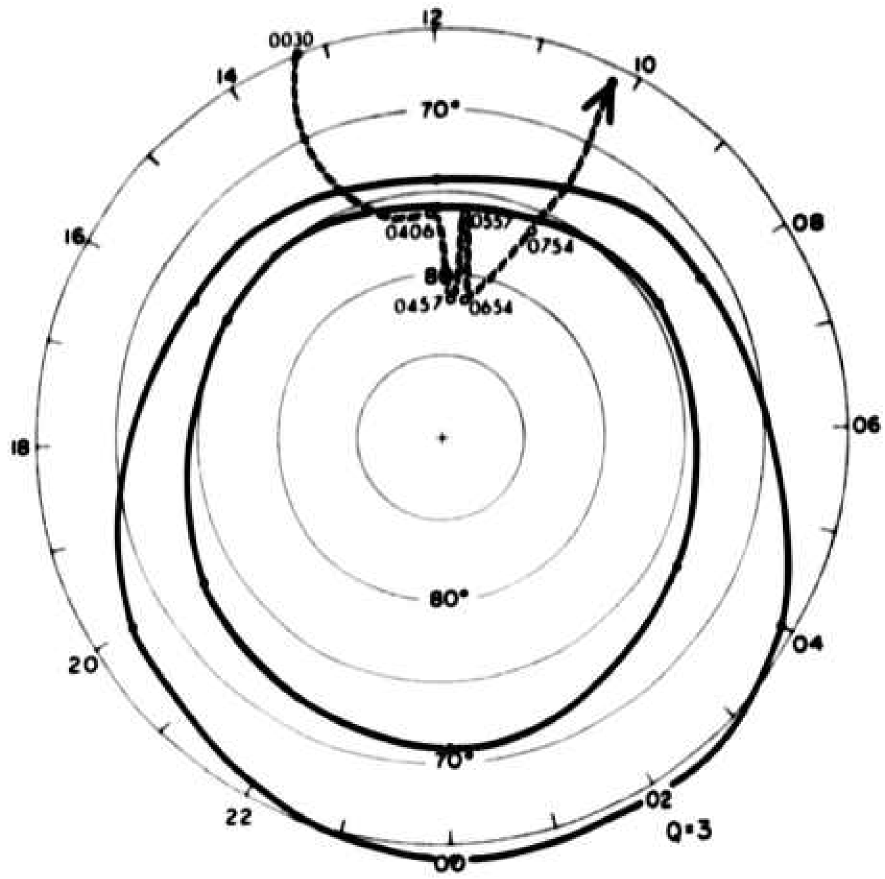
An example of a constant C.G. local time flight is the flight of 8 January 1970 shown in Figure 2. This flight originated in Eielson AFB, Alaska, and terminated in Keflavik, Iceland. It stayed within 2 hours of C.G. local noon for a duration of approximately 10 hours, simultaneously scanning in latitude. C.G. local midnight flights between Labrador and Alaska have maintained the midnight sector of the oval for similar periods of time. However since the midnight oval is at lower

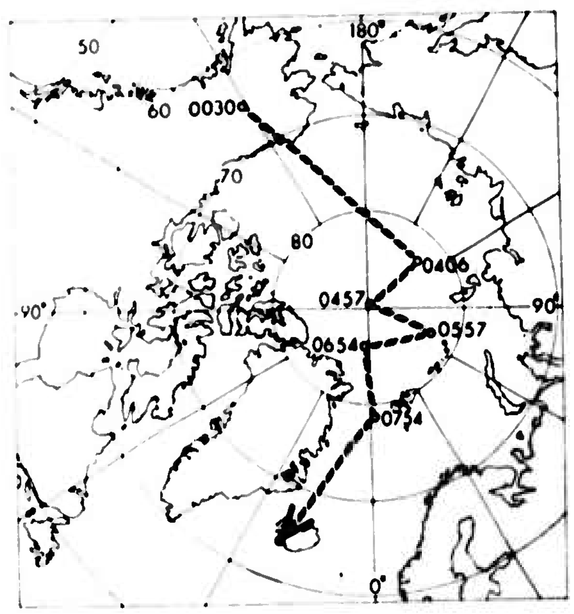




18 APRIL 69

Figure 1





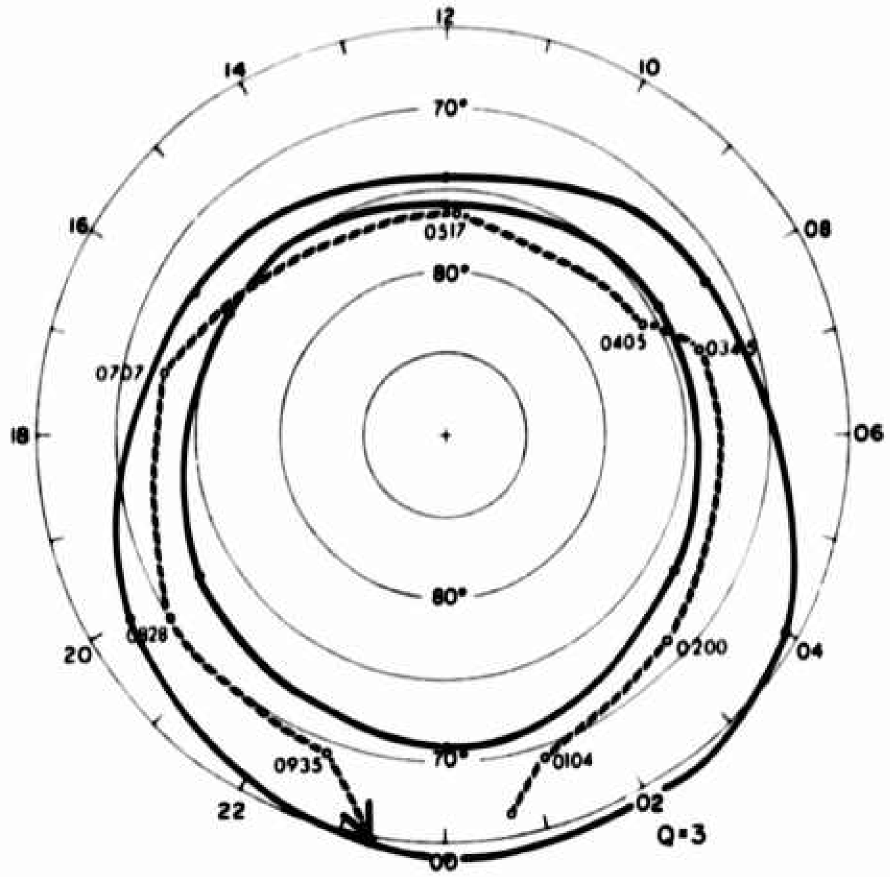
8 JAN 70

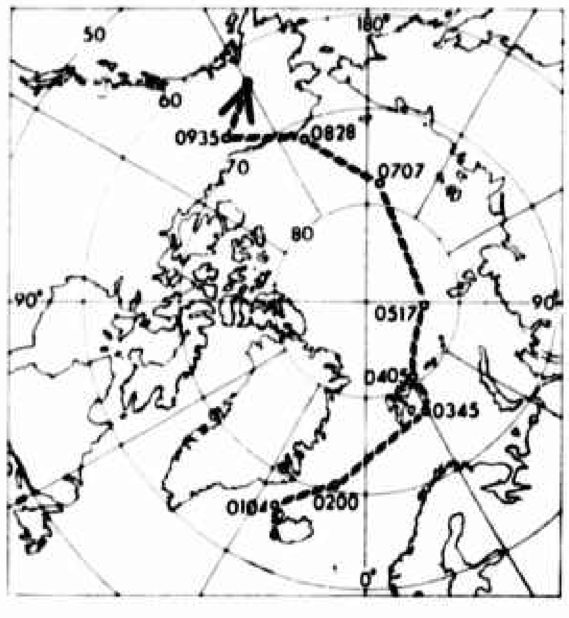
Figure 2

latitudes where the velocity of the earth is greater, the aircraft can make only very limited latitude scans, the greatest component of its velocity being required to keep up with the rotation of the earth.

6.3 Accelerated C.G. Local Time: The Circum-Oval Flight

Flying in the direction of the rotation of the earth accelerates local time. Flying along the auroral oval in this sense affords the opportunity of examining its continuity over extended sectors in a manner not possible from ground stations. The navigation problem of computing the intersection of the path of the oval over the earth with that of a rapidly moving aircraft is in general quite complicated, but greatly simplified by use of the auroral oval plotter. With its aid it has been possible to achieve a flight completely around the oval (less about one hour). This flight (5 January 1970 shown in Figure 3) which originated in Keflavik, Iceland, and terminated in Eielson, Alaska, succeeded for the first time in examining the continuity of the oval as a whole (Buchau et al, 1970).





5 JAN 70

Figure 3

Acknowledgments

The author wishes to thank the following: S.-I. Akasofu is the originator of the mechanical rotating oval model of which this plotter is a conceptual descendant. J. Buchau and R.A. Wagner have given invaluable aid throughout the entire evolution of the Auroral Oval Plotter into a working instrument.

Preceding page blank

References

Buchau, J., Whalen, J.A., and Akasofu, S.-I. (1969) Airborne observation of the midday aurora J. Atmos. Terr. Phys. 31:1021-1026.

Buchau, J., Whalen, J.A., and Akasofu, S.-I. (1970) On the Continuity of the Auroral Oval, submitted to J. Geophys. Res.

Feldstein, Y.I. and Starkov, G.V. (1967) Dynamics of auroral belt and polar geomagnetic disturbances Planet. Space Sci. 15:209-229.

Fukushima, N. (1965) Seasonal change of auroral zone in corrected geomagnetic latitudes Rep. Ionosph. Space Res. Japan 19:367-370.

Gustafsson, G. (1967) On the orientation of auroral arcs Planet. Space Sci. 15:277-294.

Hakura, Y. (1964) Patterns of polar cap blackouts drawn in geomagnetic coordinates corrected by the higher terms of spherical harmonic development Rep. Ionosph. Space Res. Japan 18:345-365.

Hakura, Y. (1965) Tables and maps of geomagnetic coordinates corrected by the higher order spherical harmonic terms Rep. Ionosph. Space Res. Japan 19:121-157.

Hultqvist, B. (1958a) The spherical harmonic development of the geomagnetic field, epoch 1945, transformed into rectangular geomagnetic coordinate systems Ark Geofy. 3:53-61.

Hultqvist, B. (1958b) The geomagnetic field lines in higher approximation Ark. Geofys. 3:63-77.

Hultqvist, B. (1959) Auroral isochasms Nature 183:1478.

Hultqvist, B. and Gustafsson, G. (1960) On the magnetic time dependence of the auroral zone currents J. Atmos. Terr. Phys. 19:246-259.

Maehlum, B. N. (1968) Universal-time control of the low-energy electron fluxes in the polar regions J. Geophys. Res. 73:3459-3468.

References

Mayaud, P.N. (1960) Un Noveau Systems de Coordonnees Magnetigues pour l'Etude de la Haute Atmosphere: les Coordonnees de l'anneau Equatorial Ann. Geophysique 16:278-288.

McNish, A.G. (1936) Geomagnetic coordinates for the entire earth Terr. Magn. 41:37-43.

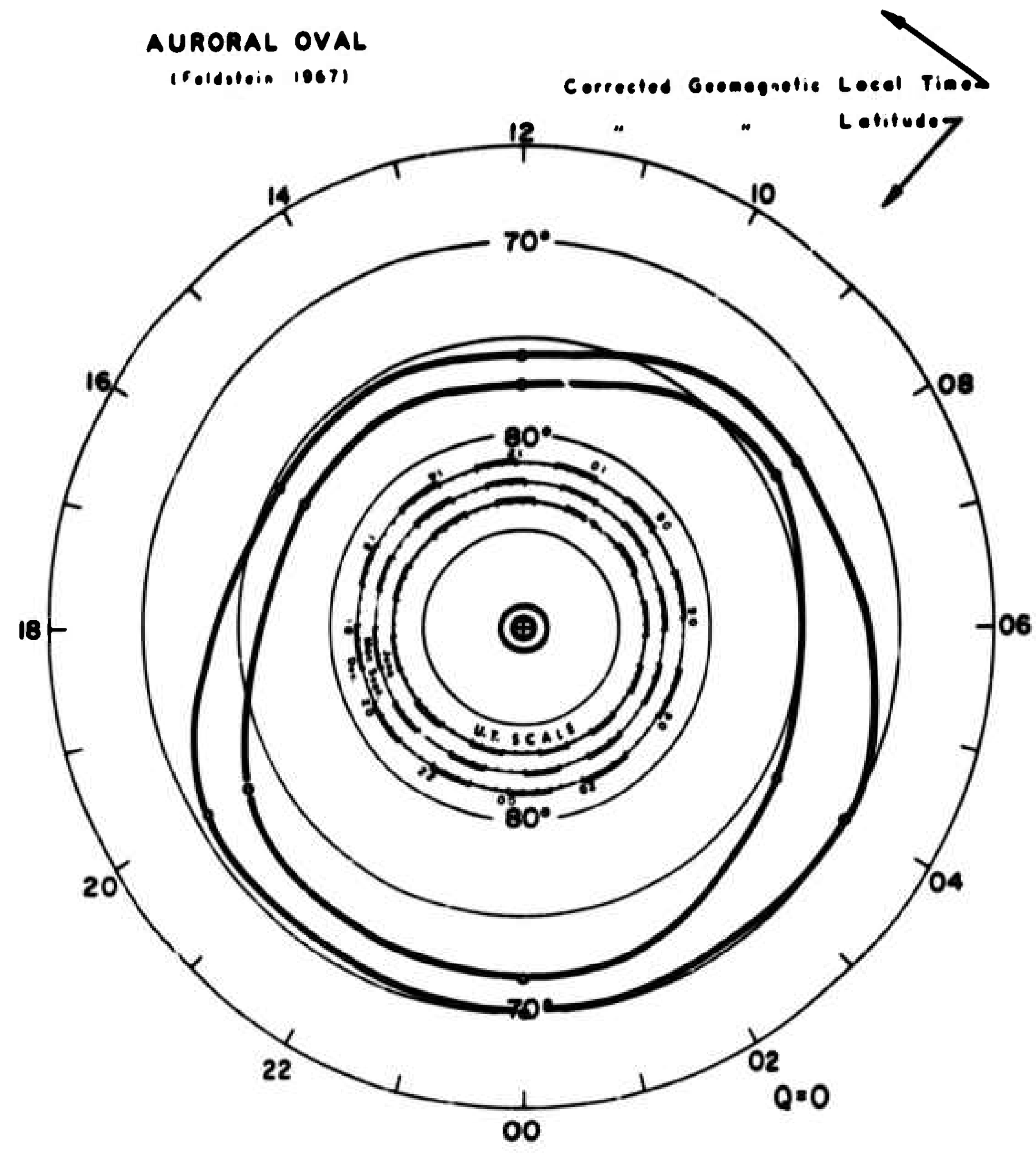
Penndorff, R. (1968) The Antarctic Ionosphere Part A: Survey and Basic Information, Antarctic Research and Data Analysis Scientific Report No. 28, AVSSD-0053-68-CR, Contract NSF-C-515, Office of Antarctic Programs, National Science Foundation, Wash., D.C.

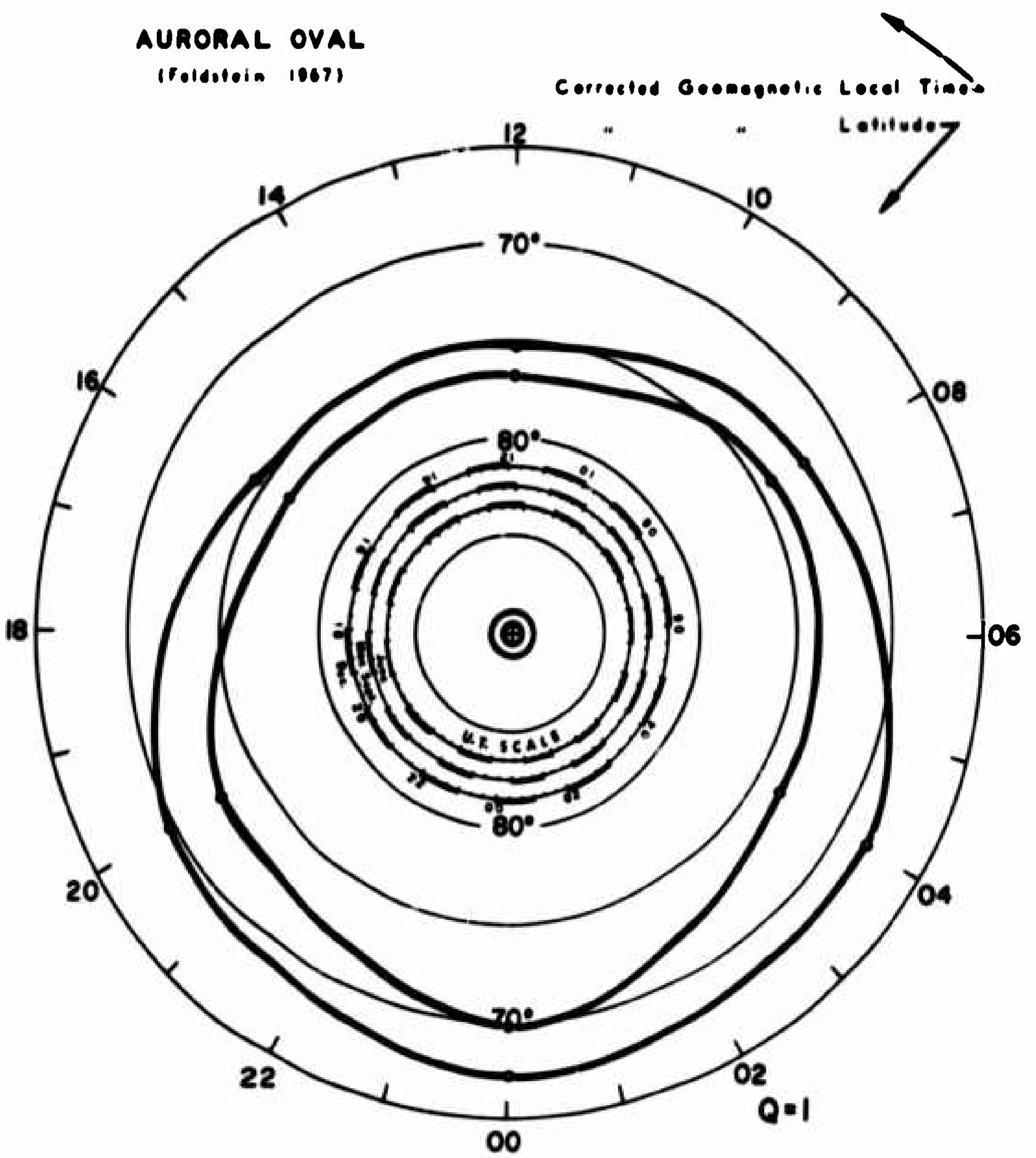
Sandford, B.P. (1968) Variations of auroral emissions with time, magnetic activity, and the solar cycle J. Atmos. Terr. Phys. 30:1921-1942.

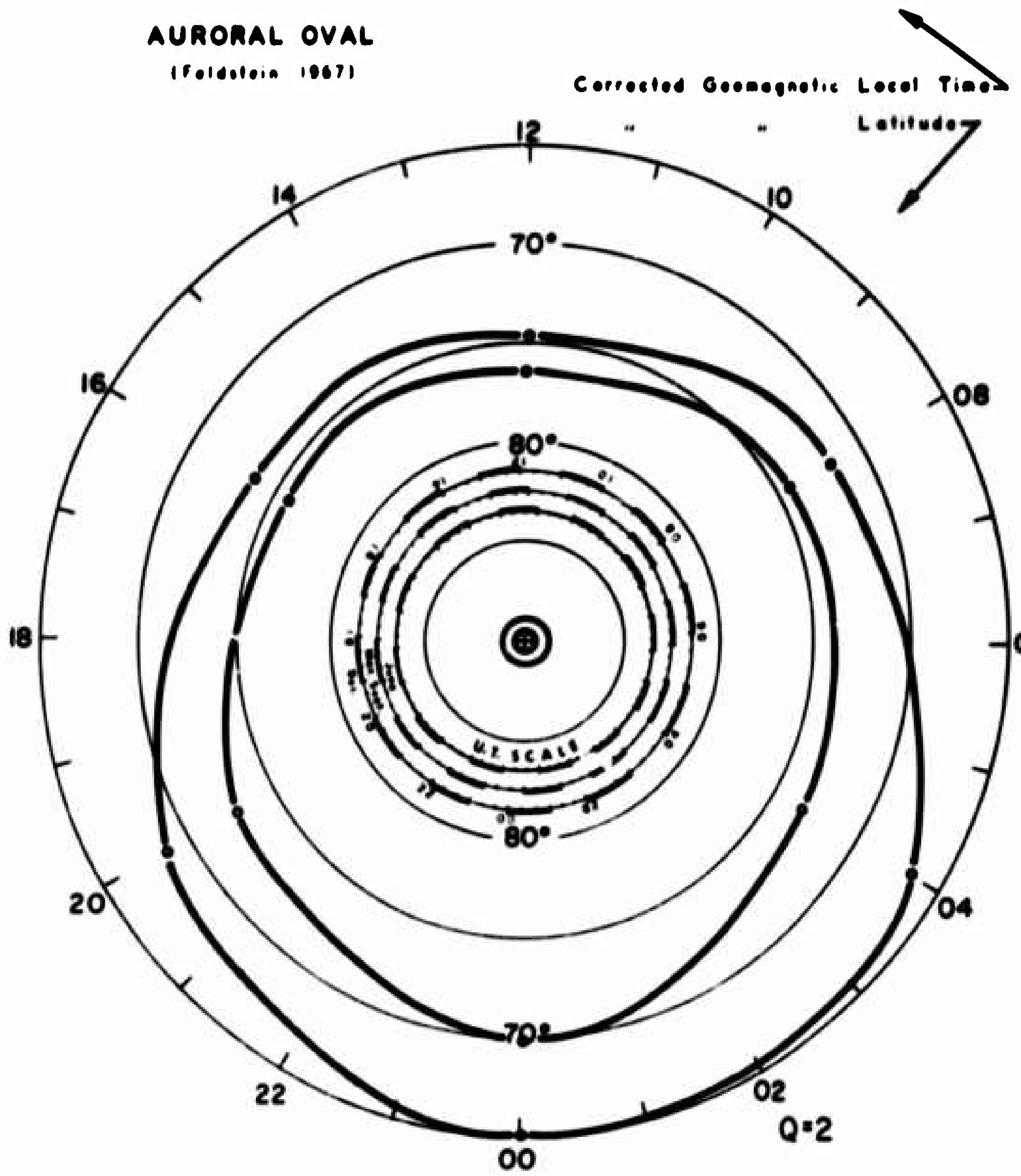
Whalen, J.A., Buchau, J., and Wagner, R.A. (1970) Noontime Aurora, Discrete and Continuous, Detected by Airborne Ionospheric and Optical Measurements, submitted to J. Atmos. Terr. Phys.

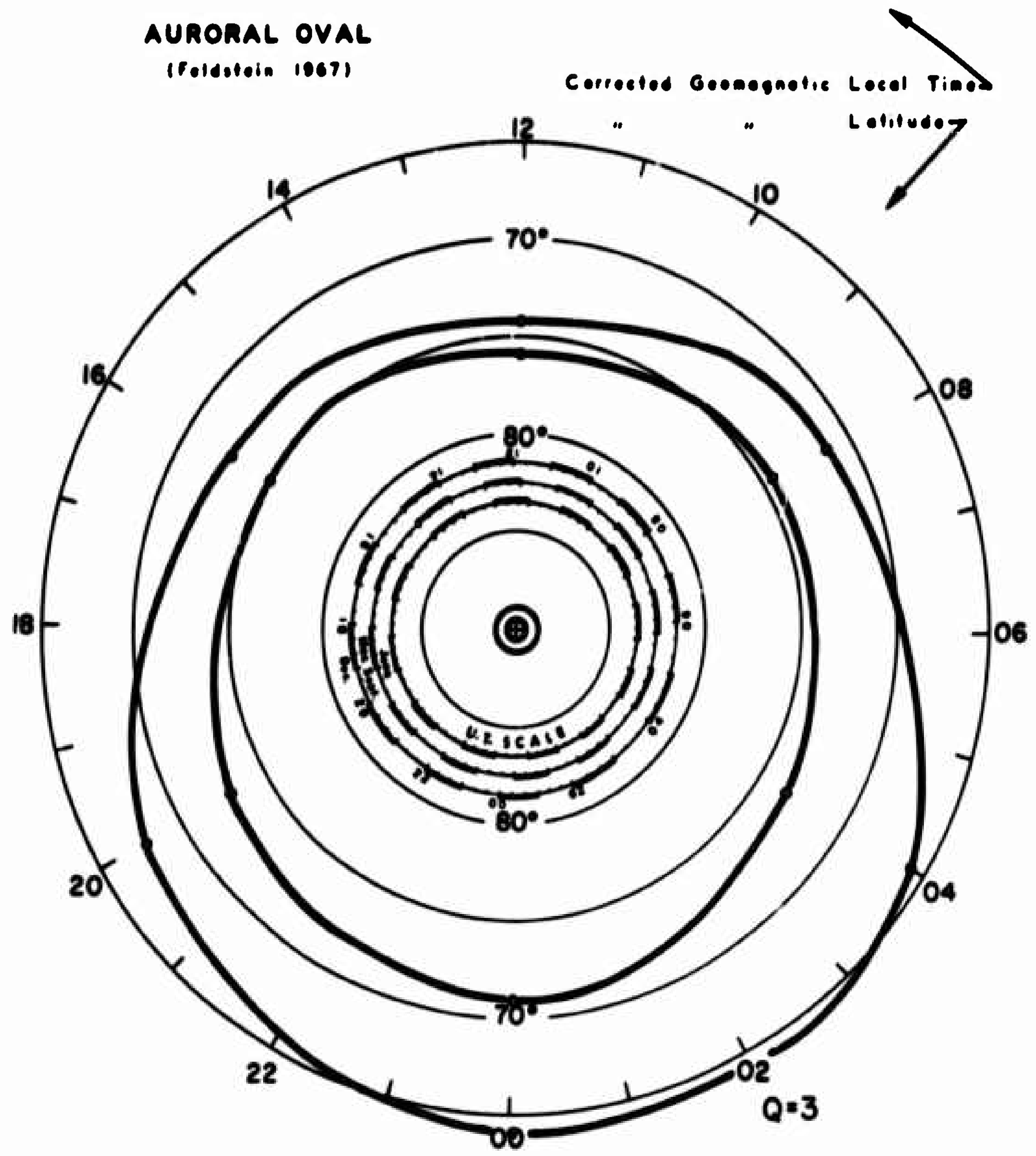
Appendix A

Auroral Oval Plots

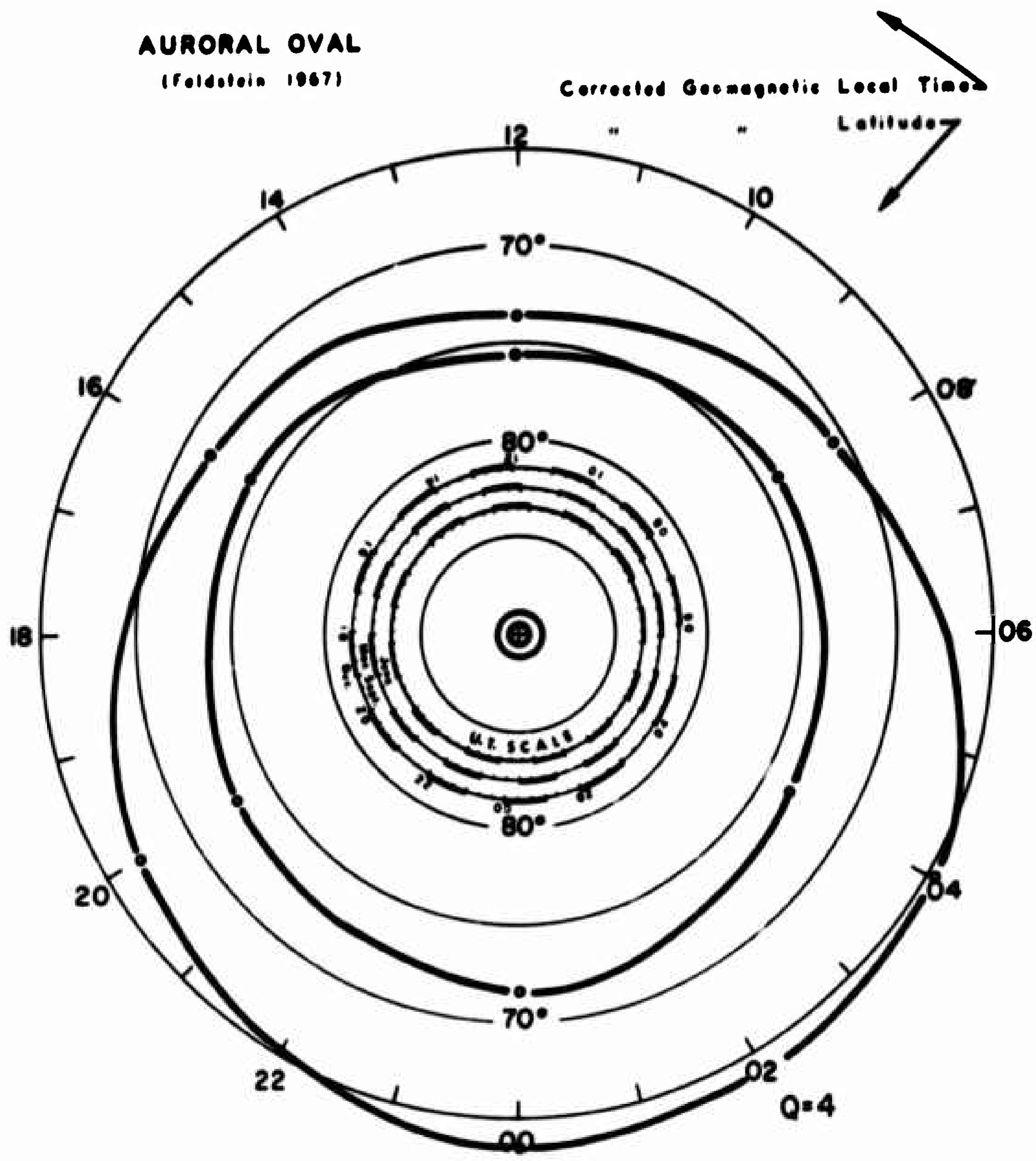

AURORAL OVAL
(Feldstein 1967)
Corrected Geomagnetic Local Time
" " Latitude
12
14
10
16
08
18
06
20
04
22
02
00
70°
80°
U.T. SCALE
Q=0

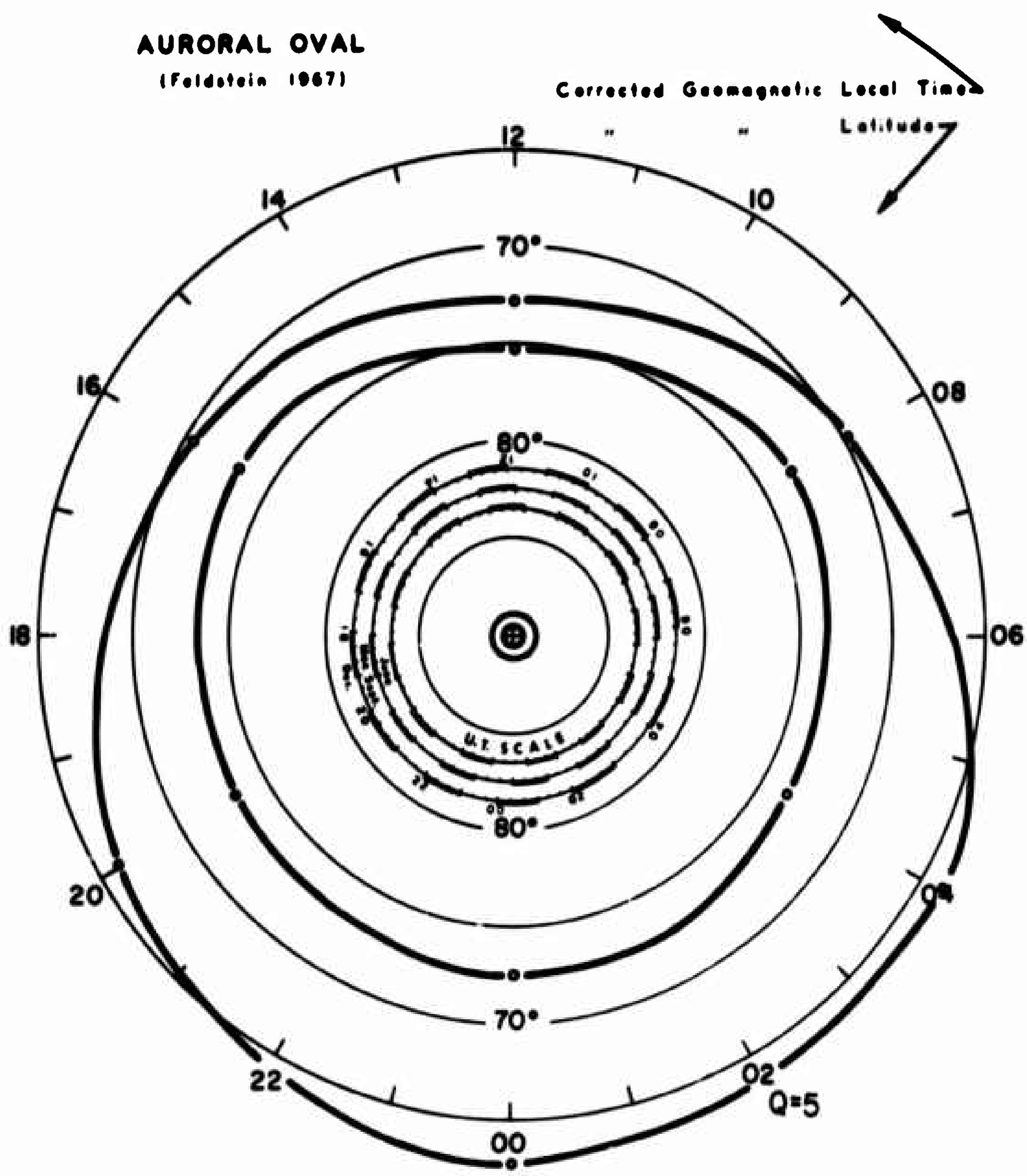

AURORAL OVAL
(Feldstein 1967)
Corrected Geomagnetic Local Time
" " Latitude
12
14
10
16
08
18
06
20
04
22
02
00
70°
80°
80°
70°
U.T. SCALE
Q=1


AURORAL OVAL
(Feldstein 1967)
Corrected Geomagnetic Local Time
" " Latitude
12
14
10
70°
16
08
80°
18
06
U.T. SCALE
80°
20
04
70°
22
02
00
Q=2


AURORAL OVAL
(Feldstein 1967)
Corrected Geomagnetic Local Time
" " Latitude
12
14
10
16
08
18
06
20
04
22
02
00
70°
80°
80°
70°
U.T. SCALE
Q=3

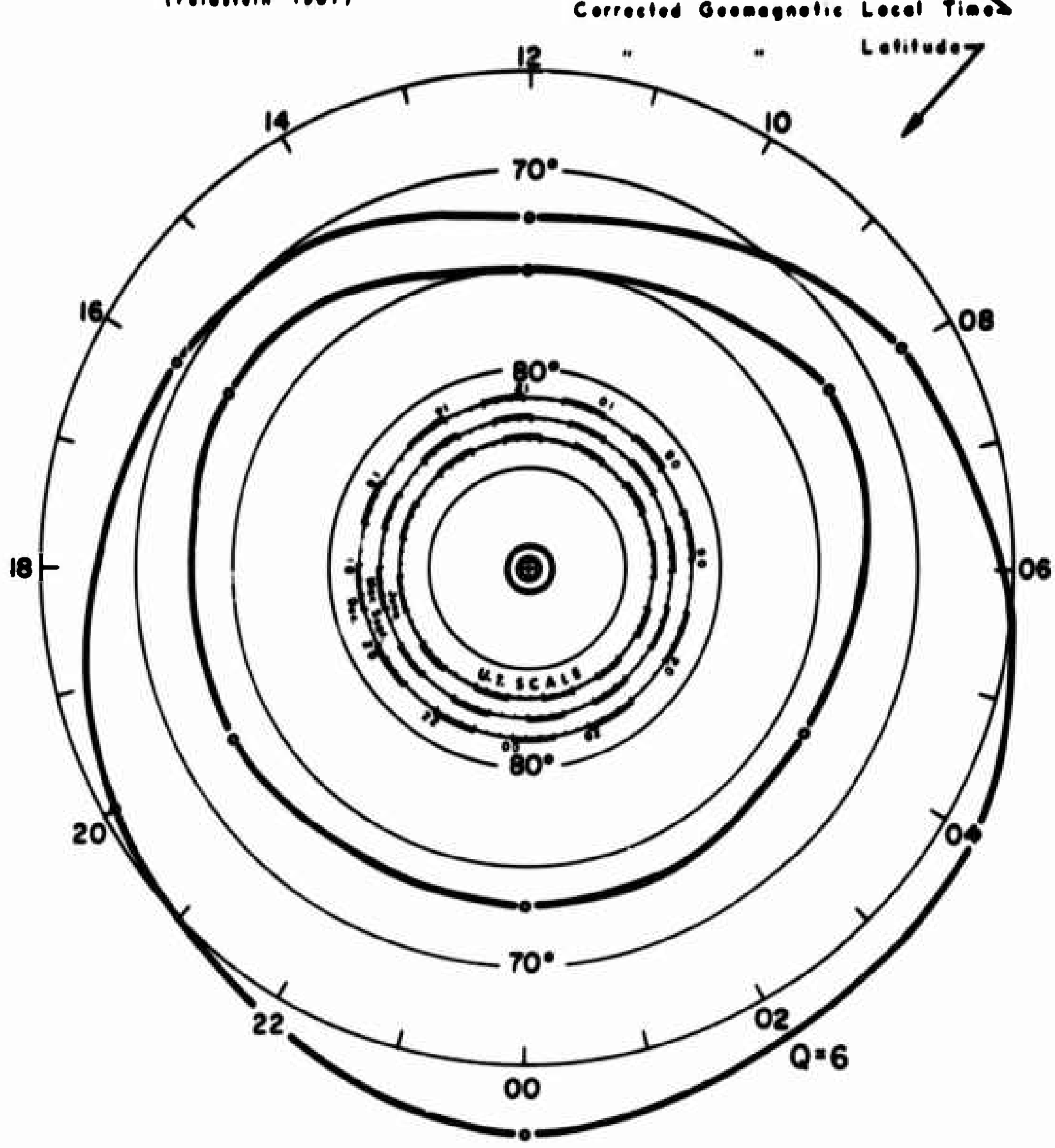
A6

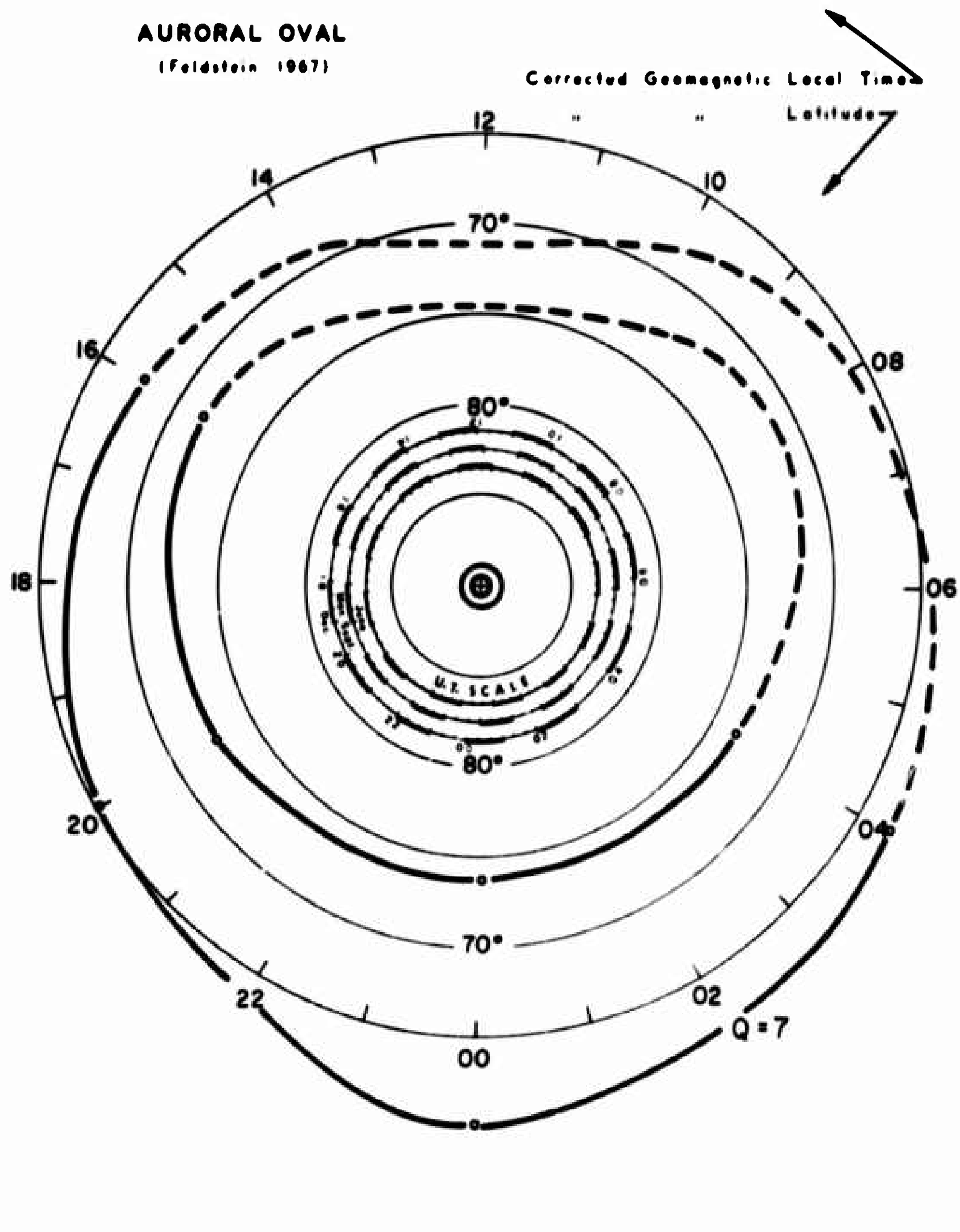

AURORAL OVAL
(Feldstein 1967)
Corrected Geomagnetic Local Time
" " Latitude
12
14
10
16
08
18
06
20
04
22
02
00
70°
80°
U.T. SCALE
Q=4

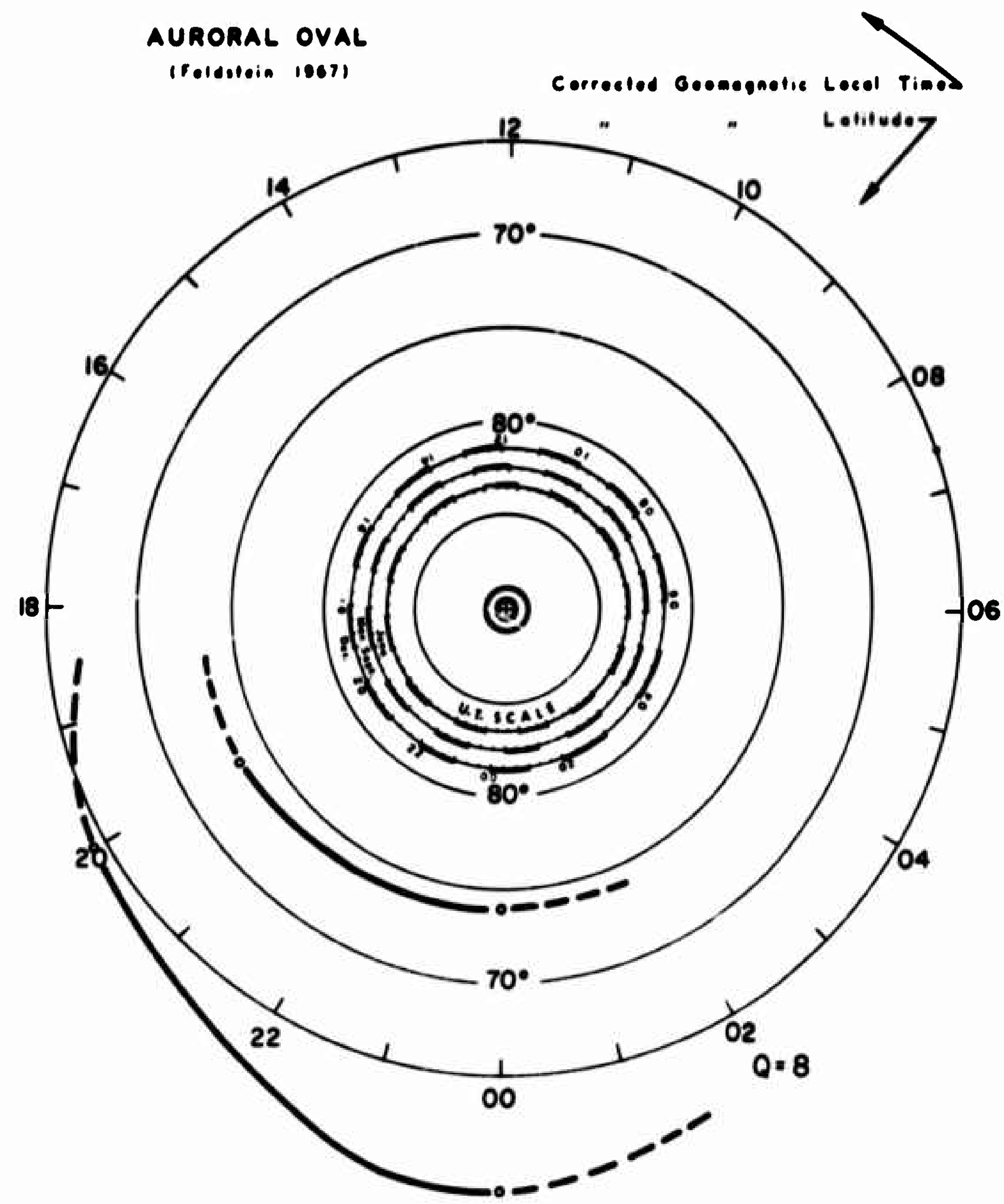

AURORAL OVAL
(Feldstein 1967)
Corrected Geomagnetic Local Time
" " Latitude
12
14
10
16
08
18
06
20
04
22
02
00
70°
80°
80°
70°
U.T. SCALE
Q=5

AURORAL OVAL

(Feldstein 1967)




AURORAL OVAL
(Feldstein 1967)
Corrected Geomagnetic Local Time
" " Latitude
12
14
10
16
08
18
06
20
04
22
02
00
70°
80°
80°
70°
U.T. SCALE
Q = 7


AURORAL OVAL
(Feldstein 1967)
Corrected Geomagnetic Local Time
" " Latitude
12
14
10
16
08
18
06
20
04
22
02
00
70°
80°
U.T. SCALE
Q=8

DIRECTION SHEET

DIRECTIONS

The AURORAL OVAL PLOTTER consists of two elements: (1) the transparent map titled 'Geographic Coordinates plotted in Corrected Geomagnetic Coordinates,' which is enclosed in this envelope, and (2) one of the nine auroral oval plots. Both elements have been constructed to rotate about the same axis (the center point of the C.G. poles).

Plotter Assembly

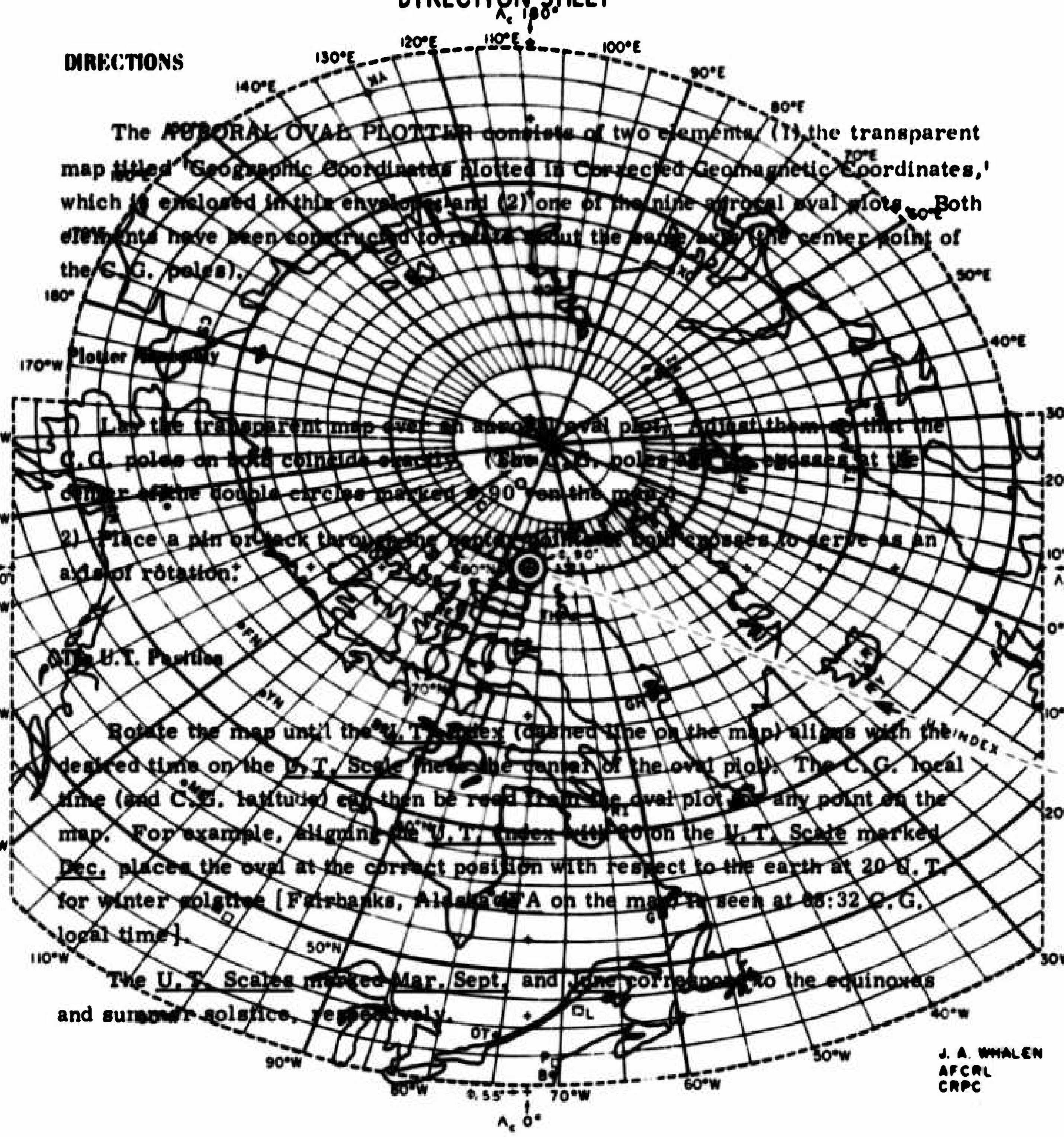
1) Lay the transparent map over an auroral oval plot. Adjust them so that the C.G. poles on both coincide exactly. (The C.G. poles are the crosses at the center of the double circles marked Φ 90° on the map.)

2) Place a pin or tack through the point where both crosses to serve as an axis of rotation.

3) The U.T. Position

Rotate the map until the U.T. Index (dashed line on the map) aligns with the desired time on the U.T. Scale (near the center of the oval plot). The C.G. local time (and C.G. latitude) can then be read from the oval plot for any point on the map. For example, aligning the U.T. Index with 20 on the U.T. Scale marked Dec. places the oval at the correct position with respect to the earth at 20 U.T. for winter solstice [Fairbanks, Alaska (FA on the map) is seen at 08:32 C.G. local time].

The U.T. Scales marked Mar. Sept. and June correspond to the equinoxes and summer solstice, respectively.



GEOGRAPHIC COORDINATES plotted in CORRECTED GEOMAGNETIC COORDINATES

DIRECTION SHEET

DIRECTIONS

The AURORAL OVAL PLOTTER consists of two elements: (1) the transparent map titled 'Geographic Coordinates plotted in Corrected Geomagnetic Coordinates,' which is enclosed in this envelope; and (2) one of the nine auroral oval plots. Both elements have been constructed to rotate about the same axis (the center point of the C.G. poles).

Plotter Assembly

1) Lay the transparent map over an auroral oval plot. Adjust them so that the C.G. poles on both coincide exactly. (The C.G. poles are the crosses at the center of the double circles marked $\Phi_c 90^o$ on the map.)

2) Place a pin or tack through the center points of both crosses to serve as an axis of rotation.

The U.T. Position

Rotate the map until the U.T. Index (dashed line on the map) aligns with the desired time on the U.T. Scale (near the center of the oval plot). The C.G. local time (and C.G. latitude) can then be read from the oval plot for any point on the map. For example, aligning the U.T. Index with 20 on the U.T. Scale marked Dec. places the oval at the correct position with respect to the earth at 20 U.T. for winter solstice [Fairbanks, Alaska (FA on the map) is seen at 08:32 C.G. local time].

The U.T. Scales marked Mar. Sept. and June correspond to the equinoxes and summer solstice, respectively.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*	2a. REPORT SECURITY CLASSIFICATION
Air Force Cambridge Research Laboratories (CRP) L.G. Hanscom Field Bedford, Massachusetts 01730	Unclassified 2b. GROUP

3. REPORT TITLE
AURORAL OVAL PLOTTER AND NOMOGRAPH FOR DETERMING CORRECTED GEOMAGNETIC LOCAL TIME, LATITUDE, AND LOGITUDE FOR HIGH LATITUDES IN THE NORTHERN HEMISPHERE

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Scientific. Interim.

5. AUTHOR(S) *(First name, middle initial, last name)*
James A. Whalen

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
27 July 1970	30	17

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT, TASK, WORK UNIT NOS. 5631-14-01	AFCRL-70-0422
c. DOD ELEMENT 61102F	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* ERP No. 327
d. DOD SUBELEMENT 681310	

10. DISTRIBUTION STATEMENT
1—This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
TECH, OTHER	Air Force Cambridge Research Laboratories (CRP) L.G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

A nomographic computer is presented which graphically converts geographical coordinates and universal time into geomagnetic coordinates and geomagnetic local time in the Corrected Geomagnetic system of Hultqvist. The computer is formulated as a map of high latitudes in the Northern Hemisphere on which the position of the auroral oval can be projected directly for any time of day, for any magnetic activity, with account being taken of seasonal variation of the geomagnetic local time coordinate. Instructions for its use, discussion of its accuracy, and examples of its application are given.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Auroral Oval						
Nomograph						
Geomagnetic Coordinates						
Geomagnetic Local Time						
Arctic Ionosphere						
Airborne Research						

Unclassified
Security Classification